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(71) Applicant
Chas A Blatchford & Sons Limited

(Incorporated in the United Kingdom)

Lister Road, Basingstoke, Hampshire, RG22 4AH, United Kingdom

(72) Inventor
Andrew John Sear Evans

(74) Agent and/or Address for Service
Withers & Rogers
4 Dyer's Buildings, Holborn, London, EC1N 2JT, United Kingdom

(54) **Moulding compound and a method of manufacture**

(57) A method of manufacturing a moulding compound for producing fibre-reinforced plastics articles makes use of scrap prepreg material, i.e. carbon, aramid or other fibre material pre-impregnated with a thermosetting plastics material in a partly cured state. The scrap material, which may be in the form of woven or unidirectional cloth, or fibre tows or braid, is cooled at least to a temperature of –50 degrees C and milled at low temperature to yield fragments of the fibre/plastics mixture in which the average filament length is preferably in the range of from 1 to 2 mm. These fragments substantially retain the fibre-to-plastics matrix proportions of the original material and can be used in a dough-moulding, process to yield isotropic fibre reinforced plastics articles of complex shape.

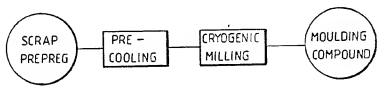

Fig.1.

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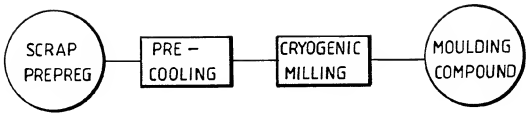

Fig.1.

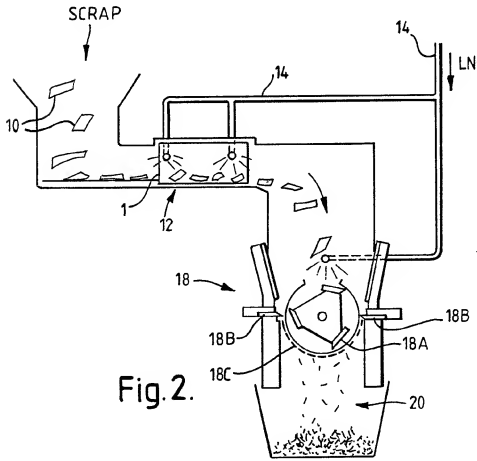

Fig.2.

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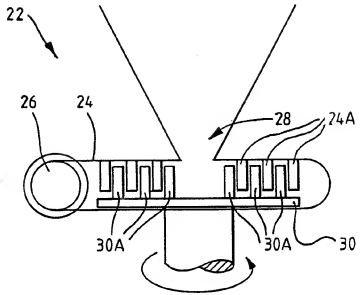

Fig.3.

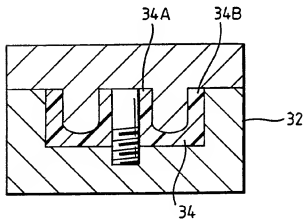

Fig.4.

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A Moulding Compound and a Method of Manufacturing the Compound

This invention relates to a moulding compound which is a fibre and plastics composite and to a method of manufacturing the compound.

It is well known to mould composites containing a thermosetting plastics matrix and reinforcing carbon, aramid or other fibres. The fibres may be used in the form of a woven cloth, fibre tows, or braid. To simplify the moulding process the materials of the composite are commonly supplied as a mixture of plastics and fibre in the proportions required for moulding, the plastics material being in a partly cured, tacky state. This impregnated mixture is generally known as "prepreg". Moulding begins with the cutting of the prepreg to suitable sizes and shapes depending on the size and shape of the article to be moulded, and is followed by the laying of the material in or on a mould. Moulding is performed by subjecting the material to heat, generally under pressure, yielding an article which has a considerably higher strength-to-weight ratio than most metals.

Prepreg materials, particularly those containing carbon or aramid fibres, are, however, expensive. In cutting such a material to size, a considerable quantity is wasted, particularly when the fibres are in the form of a cloth, since the offcuts are usually too small to be used in further mouldings. Often, the proportion of the original material represented by offcuts is as high as 25 per cent, and unless they can be used in making small components, they have conventionally been discarded as unusable scrap.

It is one of the objects of this invention to make use of such scrap material.

According to a first aspect of this invention, a method of manufacturing a moulding compound which is a fibre and plastics composite comprises the steps of:

(i) providing a mixture of fibres impregnated with a plastics matrix in a flexible state; (ii) cooling the mixture to a temperature less than or equal to, -50 degrees celsius; and (iii) milling the mixture while it is still at a temperature less than or equal to -50 degrees celsius to yield a compound having fibres which are shorter than those of the mixture provided in step (i). The filaments lengths of the compound are typically in the range of from 0.2mm to 10mm. Material so treated retains the original proportions of plastics and fibre materials and can, if required, be mouldedto form articles which are substantially isotropic, i.e. in which thefibres are to a large degree randomly oriented.

The milled compound is particularly suitable for producing articles by compression moulding, and, unlike anisotropic prepregs, possesses good flow characteristics and can be moulded around sharp corners. Since the proportions of fibre and plastics materials are largely governed by the proportions in the starting mixture, i.e. prior to milling, it is possible to achieve a higher fibre content than in a typical conventional dough moulding compound, giving a superior strength isotropic material. The starting material can be glass-fibre prepreg, but in general higher strength can be obtained using carbon or aramid as the reinforcing fibre material.

The method is primarily applicable to composites with a thermosetting plastics matrix such as epoxy resin or heat-curing polyester, the matrix prior to cooling being in a partly cured flexible state. The low temperatures used, as well as making the material relatively brittle for the milling process, prevent the onset of curing which can otherwise arise as a result of heat generated in the milling operation. It is also possible to treat injection mouldable thermoplastics-

based composites in accordance with the invention, the cooling step rendering the matrix relatively brittle.

The invention also includes according to a second aspect thereof, a moulding compound produced by the method referred to above and comprising a quantity of randomly oriented fragments each comprising a bundle of thermosetting plastics-coated fibre filaments with filament lengths in the range of from 0.2mm to 10mm.

According to a third aspect of the invention, there is provided a method of moulding a fibre-reinforced plastics article comprising placing in a mould a quantity of fragments each comprising a bundle of carbon or aramid fibres coated with a thermosetting plastics material in a partly cured state and having filament lengths in the range of from 0.2mm to 10mm, and heating the mass of fragments in the mould under pressure to cure the plastics material, thereby yielding a substantially isotropic fibre-reinforced component.

The invention will now be described by way of example with reference to the drawings in which:-

Figure 1 is a block diagram illustrating the principle of a preferred method in accordance with the invention for producing a moulding compound;

Figure 2 is a diagram of apparatus for carrying out the method of Figure 1, including a rotating blade granulator;

Figure 3 is a diagrammatic cross-section of a pin-disc mill; and

Figure 4 is a diagrammatic cross-section of a mould assembly for moulding an article from a moulding compound produced in accordance with the invention.

Referring to Figures 1 and 2, the starting material used for a process in accordance with the invention may be woven cloth, tows or braid of carbon or other fibre materials, impregnated with a thermosetting plastics material using, for example, a resin dipping technique. The applicants have in particular used scrap offcuts 10

of carbon fibre woven cloth impregnated with a 'B' stage epoxy resin matrix. However, virgin material can be used providing it is cut into suitable pieces for the process to be described below. Care must be taken that the material used is within its shelf life.

After having had the release paper removed, the prepreg offcuts 10 are fed into a cryogenic pre-cooler 12 using liquid nitrogen as the cooling medium at -196°C, supplied via pipes 14. The offcuts are tumbled in a cooling vessel 16 whilst the liquid nitrogen is injected into the vessel. Once the charge has been sufficiently chilled, it is immediately transferred to a mill 18, which may be of the type having a plurality of cutting blades 18A formed as a rotatable assembly with the cutting edges of the blades defining a cylindrical surface centred on the axis of rotation. Such a mill is often referred to as a granulator. As they rotate, the blades successively engage stationary blades 18B mounted parallel to the axis of rotation with a shearing action. A mesh 18C with a predetermined aperture size is mounted beneath the blades to allow passage only of milled fragments 20 of less than a predetermined size. In this way the fibre lengths of the moulding compound is controlled to lie within a predetermined range.

In the preferred method in accordance with the invention the duration of the milling process and the mesh aperture size is arranged to yield fragments of impregnated fibre compound in which the filament length is mostly in the range of from 0.2mm to 6mm and preferably 1mm to 2mm.

By milling the material at a temperature less than -50°C, the tendency of substantial quantities of the material to adhere to the blades of the mill or for the plastics matrix to begin curing is largely avoided, and the effect on the blades of the abrasive nature of certain fibre matierials such as carbon and aramid

fibres can be substantially reduced due to the material being brittle at this low temperature. During the milling process the resin also protects to some extent the fibre surfaces, each filament being individually coated with plastic.

The resulting shredded compound retains the optimum ratio of fibre to plastics for maximum strength, and the fibres are "wetted" with the plastics material to the same extent as in the starting material; both of these requirements would be difficult to achieve if the fibres were coated after milling. However, if a higher resin content is required, for instance to improve the surface finish of the moulding, compatible resins may be added during the milling operation to distribute resin uniformly throughout the compound. As with conventional prepreg material the compound has a shelf life which depends on the storage temperature, and for this reason is best stored in a refrigerator.

As an alternative to a rotating blade granulator as shown in Figure 2, the milling may be performed using a pin-disc mill as shown diagrammatically in Figure 3. The pin-disc mill 22 comprises a horizontal circular chamber 24 having a tangential outlet opening 26 and a central inlet opening 28 in the centre of the chamber. Within the chamber 24 is a horizontalrotatable disc 30 having rings of upstanding pins 30A arrangedaround the axis of rotation of the disc, and, extending downwardly from the top plate of the chamber, are further rings of pins 24A located at radii such that they are situated between and adjacent the pins 30A of the rotating disc 30. Material fed into the inlet 28 must pass between the relatively rotatingpins to reach the outlet 26, and in so doing is ground into fragments of a predetermined size.

In many moulding application a weighed charge of the compound may simply be poured into one half of a mould and then compressed and heated between two mould

halves. In these circumstances the compound has been found to have good flow characteristics and to be very suitable for moulding around sharp corners, unlike cloth-based prepregs. When moulded, the compound is substantially isotropic in that the filaments are mostly randomly oriented.

The compound may be used to mould a variety of articles particularly articles of intricate shape, in which a high strength to weight ratio is needed. The applicants have used the compound to mould artificial limb components such as a component for mounting a knee joint mechanism on an artificial limb socket for an above knee amputee. A mould 32 for moulding the component is shown in section in Figure 4, the material 34 of the component being shown hatched. The component comprises a circular spacer about 10mm in thickness having a central boss 34A and outer flange 34B.

In summary, a moulding compound containing fibres coated with a thermosetting plastics material, is produced by providing a starting material comprising fibres of a filament length generally greater than 10mm, the fibres being pre-coated with the plastics material, cooling the starting material to a temperature below -50°C, and milling the material while it is still at low temperature to yield fragments in which the filaments length is in the range 0.2mm to 10mm, and preferably mostly in the range 1mm to 2mm.

The moulding compound comprises a mixture of carbon, aramid or other fibres having a filament length in the range 0.2mm to 10mm, preferably mostly in the range 1mm to 2mm, and a thermosetting plastics material. The plastics material forms a coat on the fibre filaments. The compound is preferably in the form of loose fragmentseach comprising a bundle of coated filaments, so that the fragments can be placed in a mould to form a moulded article in which the fibre filaments are substantially randomly oriented.

CLAIMS

1. A method of manufacturing a moulding compound which is a fibre and plastics composite comprising the steps of: (i) providing a mixture of fibres impregnated with plastics matrix in a flexible state; (ii) cooling the mixture to a temperature less than or equal to -50 degrees celsius; and (iii) milling the mixture while it is still at a temperature less than or equal to -50 degrees celsius to yield a compound having fibres which are shorter than those of the mixture provided in step (i).

2. A method according to claim 1, wherein the filament lengths of the milled compound are in the range of from 0.2.mm to 10mm.

3. A method according to claim 1, wherein the fibres are carbon fibres.

4. A method according to claim 1, wherein the fibres are aramid fibres.

5. A method according to claim 1, wherein the plastics matrix in the said mixture is a thermosetting plastics material which, prior to the cooling step is in a partly cured condition.

6. A method according to claim 1, wherein the plastics matrix is a thermoplastics material.

7. A method according to claim 1, wherein the mixture is woven or unidirectional prepeg cloth, tows or braid having fibres of an average filament length greater than 10mm.

8. A method according to claim 1, wherein the mixture is cooled using liquid nitrogen.

9. A method according to claim 8, wherein the mixture is cooled during milling using liquid nitrogen.

10 A method according to claim 1, wherein the milled compound comprises loose fragments each comprising a bundle of plastics coated filaments of an average filament length in the range of from 1 to 2mm.

11. A moulding compound produced according to the method of claim 1, comprising a quantity of randomly oriented fragments each comprising a bundle of thermosetting plastics-coated fibre filaments with filament lengths in the range of from 0.2mm to 10mm.

12. A compound according to claim 11, wherein the fibre filaments are carbon or aramid fibre filaments.

13. A method of moulding a fibre-reinforced plastics article comprising placing in a mould a quantity of fragments each comprising a bundle of carbon or aramid fibres coated with a thermosetting plastics material in a partly cured state and having filament lengths in the range of from 0.2mm to 10mm, and heating the mass of fragments in the mould under pressure to cure the plastics material, therebyyielding a substantially isotropic fibre-reinforced component.

14. A method of manufacturing a moulding compound, the method being substantially as herein described with reference to the drawings.

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